US009473327B2

(12) **United States Patent**
Aizawa et al.

(10) **Patent No.: US 9,473,327 B2**
(45) **Date of Patent: Oct. 18, 2016**

(54) **RADIO COMMUNICATION DEVICE, RADIO COMMUNICATION METHOD, AND RADIO COMMUNICATION SYSTEM**

(71) Applicant: **FUJITSU LIMITED**, Kawasaki-shi, Kanagawa (JP)

(72) Inventors: **Shigemi Aizawa**, Gyouda (JP); **Ichio Shimizu**, Kumagaya (JP); **Ken Hiratsuka**, Kumagaya (JP); **Hikaru Murano**, Kumagaya (JP)

(73) Assignee: **FUJITSU LIMITED**, Kawasaki (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/751,352**

(22) Filed: **Jun. 26, 2015**

(65) **Prior Publication Data**

US 2016/0065248 A1 Mar. 3, 2016

(30) **Foreign Application Priority Data**

Aug. 29, 2014 (JP) 2014-176165

(51) **Int. Cl.**
H04B 1/02 (2006.01)
H04L 25/02 (2006.01)
H04L 1/00 (2006.01)
H04L 27/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 25/022*** (2013.01); ***H04L 1/00*** (2013.01); ***H04L 27/0008*** (2013.01)

(58) **Field of Classification Search**
CPC H04B 1/00; H04B 1/02; H04W 72/08; H04W 72/0413; H01L 1/0001; H01L 1/0009; H01L 1/0019; H01L 1/20; H01L 25/022; H01L 25/0222; H01L 27/12; H01L 27/28
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,408,189 B1 6/2002 Nakamura et al.
2002/0119757 A1* 8/2002 Hamabe H04L 1/0003 455/69
2003/0021243 A1* 1/2003 Hamalainen H04L 1/0009 370/329
2003/0123477 A1* 7/2003 Gollamudi H04L 1/20 370/465
2004/0110473 A1* 6/2004 Rudolf H04L 1/0026 455/69
2015/0215069 A1* 7/2015 Lin H04L 1/0009 370/329
2016/0150524 A1* 5/2016 Ramkumar H04W 72/0413 370/329

FOREIGN PATENT DOCUMENTS

JP	2000-151482	5/2000
JP	2005-020076	1/2005
JP	2005-079905	3/2005
JP	2011-004118	1/2011
JP	2012-004876	1/2012

* cited by examiner

Primary Examiner — Thanh Le
(74) *Attorney, Agent, or Firm* — Fujitsu Patent Center

(57) **ABSTRACT**

A radio communication device includes: a processor configured to execute a program; and a memory configured to store the program, wherein the processor performs, based on the program, operations to: detect communication quality of each of a plurality of channels; and lower a first set modulation level of a first channel with the communication quality which is equal to or lower than a level and a second set modulation level of a first adjacent channel as at least one of two adjacent channels adjacent to the first channel in a frequency axis direction.

20 Claims, 12 Drawing Sheets

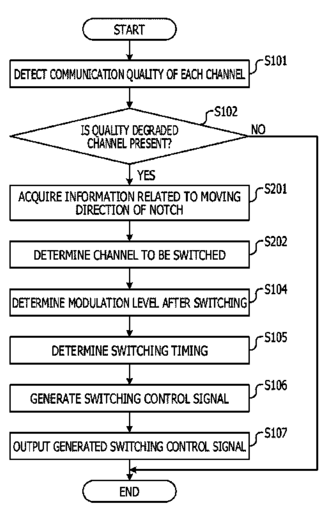


FIG. 1

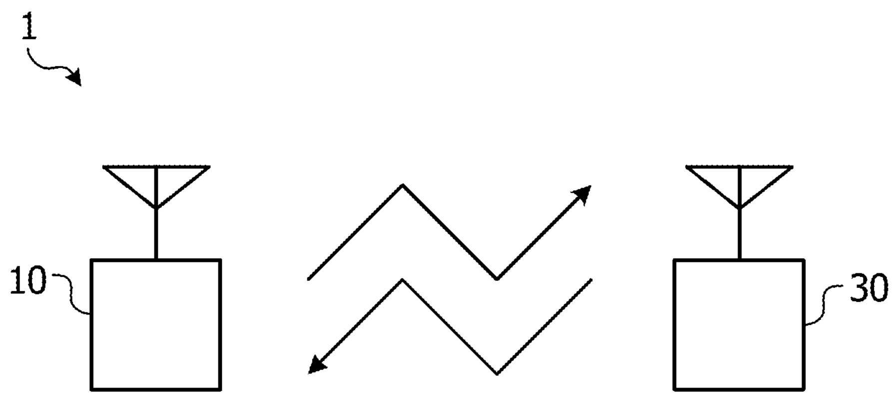


FIG. 2

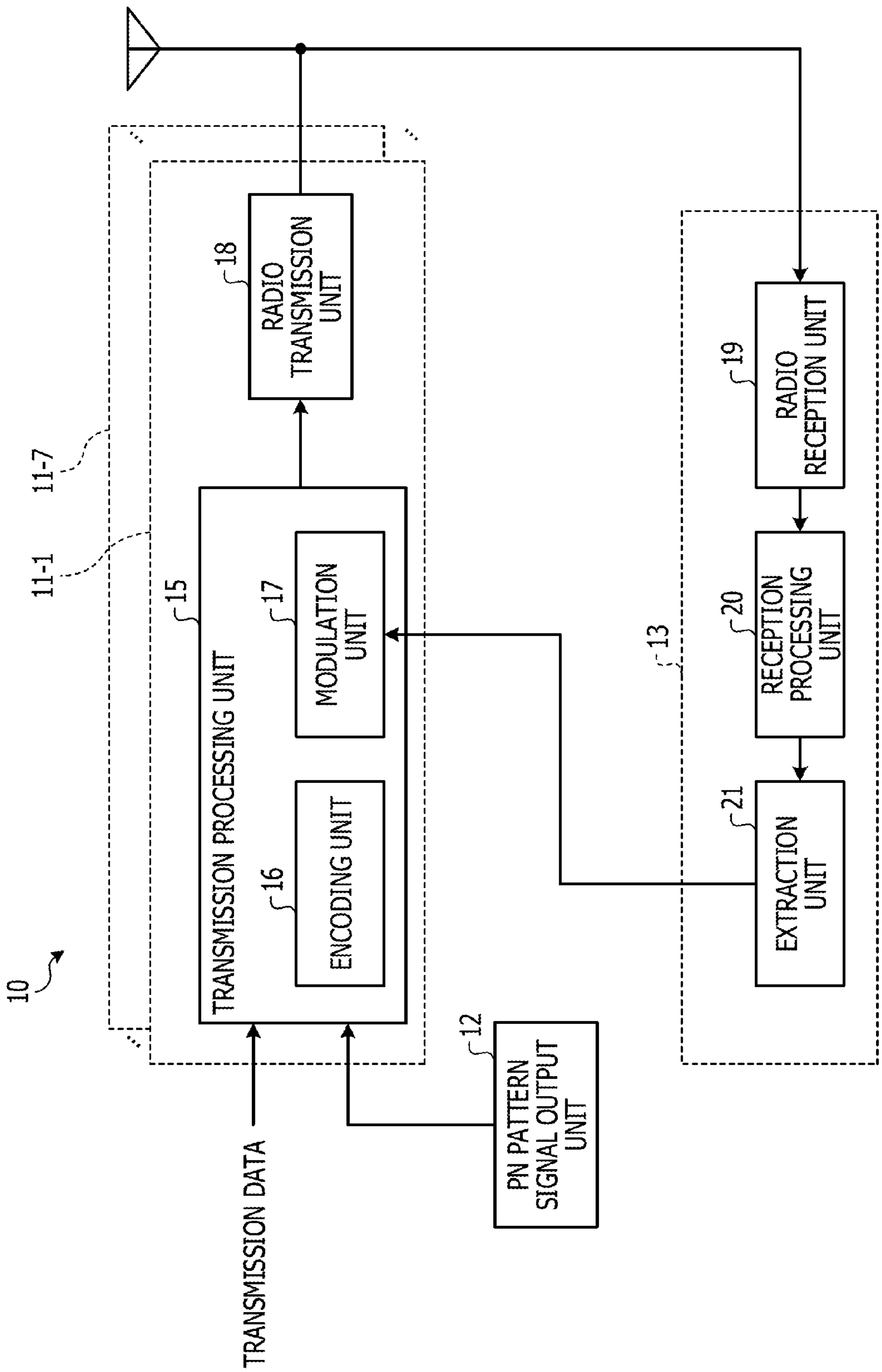

10
11-7
11-1
15
TRANSMISSION PROCESSING UNIT
16
ENCODING UNIT
17
MODULATION UNIT
18
RADIO TRANSMISSION UNIT
12
PN PATTERN SIGNAL OUTPUT UNIT
TRANSMISSION DATA
13
19
RADIO RECEPTION UNIT
20
RECEPTION PROCESSING UNIT
21
EXTRACTION UNIT

FIG. 3

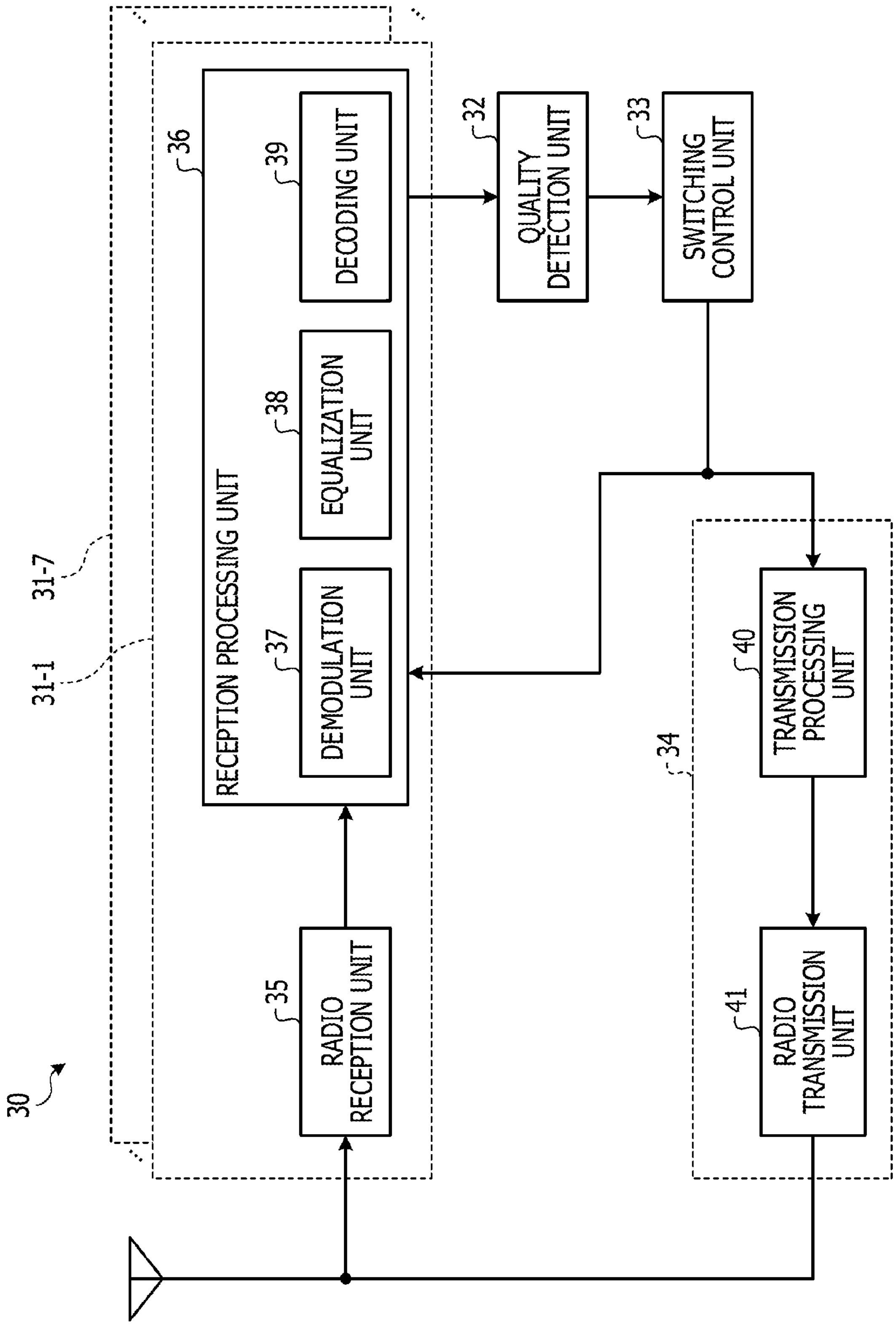

30
31-1
31-7
36
RECEPTION PROCESSING UNIT
35
RADIO RECEPTION UNIT
37
DEMODULATION UNIT
38
EQUALIZATION UNIT
39
DECODING UNIT
32
QUALITY DETECTION UNIT
33
SWITCHING CONTROL UNIT
34
40
TRANSMISSION PROCESSING UNIT
41
RADIO TRANSMISSION UNIT

FIG. 4

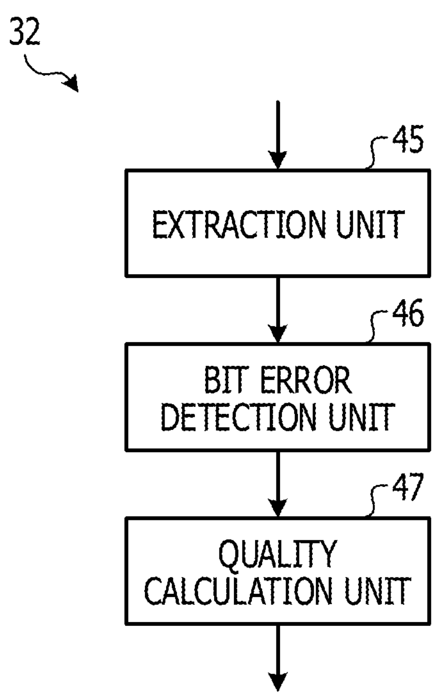

32
45
EXTRACTION UNIT
46
BIT ERROR DETECTION UNIT
47
QUALITY CALCULATION UNIT

FIG. 5

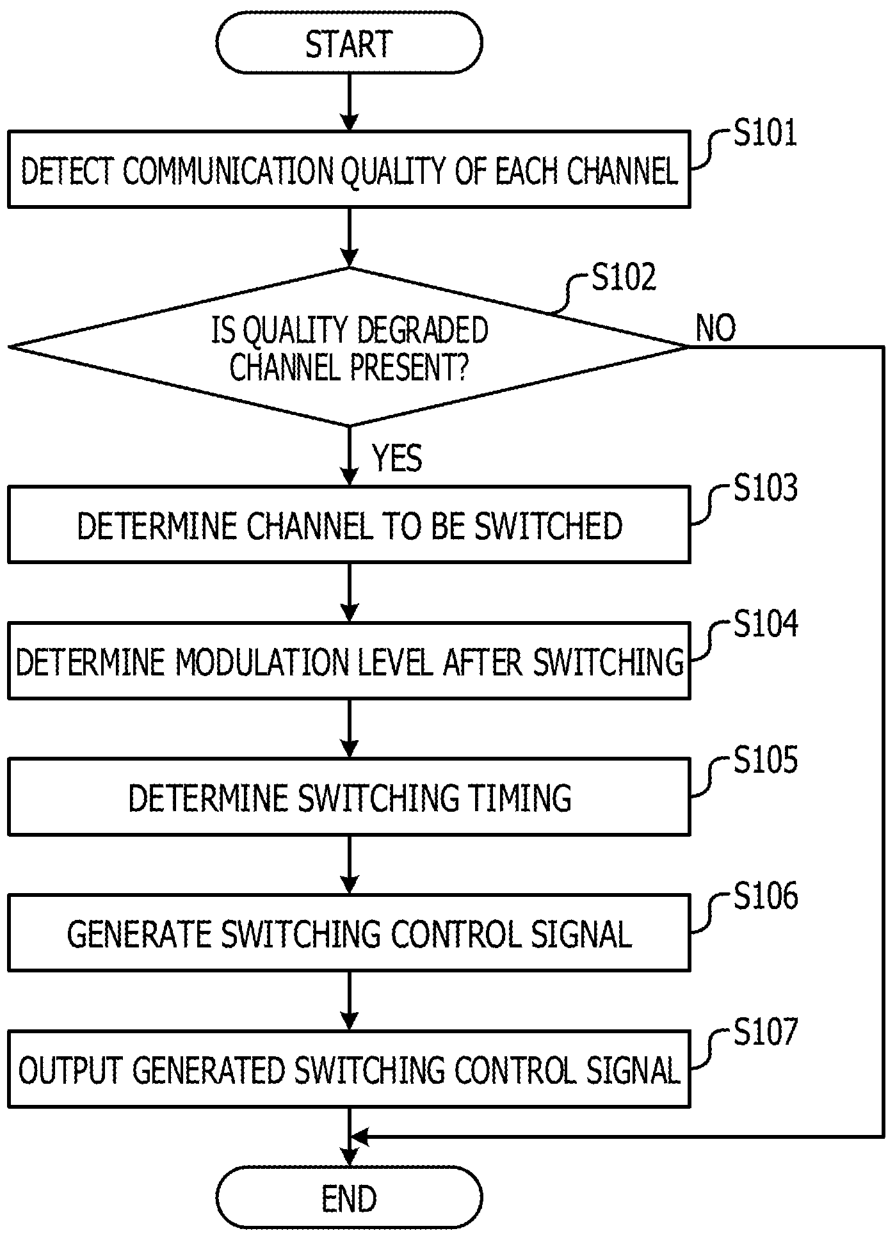

START
DETECT COMMUNICATION QUALITY OF EACH CHANNEL
S101
IS QUALITY DEGRADED CHANNEL PRESENT?
S102
NO
YES
DETERMINE CHANNEL TO BE SWITCHED
S103
DETERMINE MODULATION LEVEL AFTER SWITCHING
S104
DETERMINE SWITCHING TIMING
S105
GENERATE SWITCHING CONTROL SIGNAL
S106
OUTPUT GENERATED SWITCHING CONTROL SIGNAL
S107
END

FIG. 6

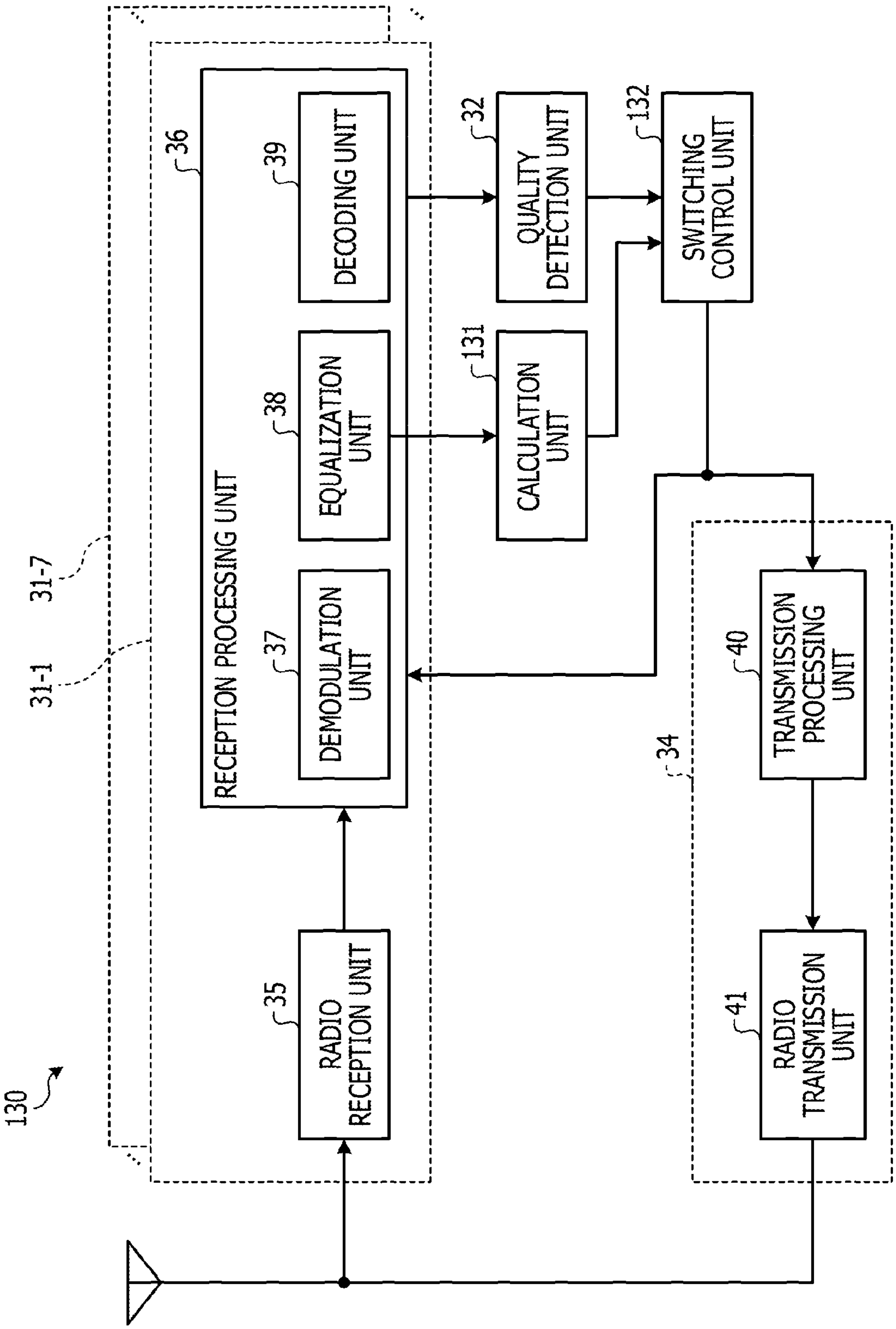

130
31-1
31-7
36
RECEPTION PROCESSING UNIT
35
RADIO RECEPTION UNIT
37
DEMODULATION UNIT
38
EQUALIZATION UNIT
39
DECODING UNIT
131
CALCULATION UNIT
32
QUALITY DETECTION UNIT
132
SWITCHING CONTROL UNIT
34
40
TRANSMISSION PROCESSING UNIT
41
RADIO TRANSMISSION UNIT

FIG. 7

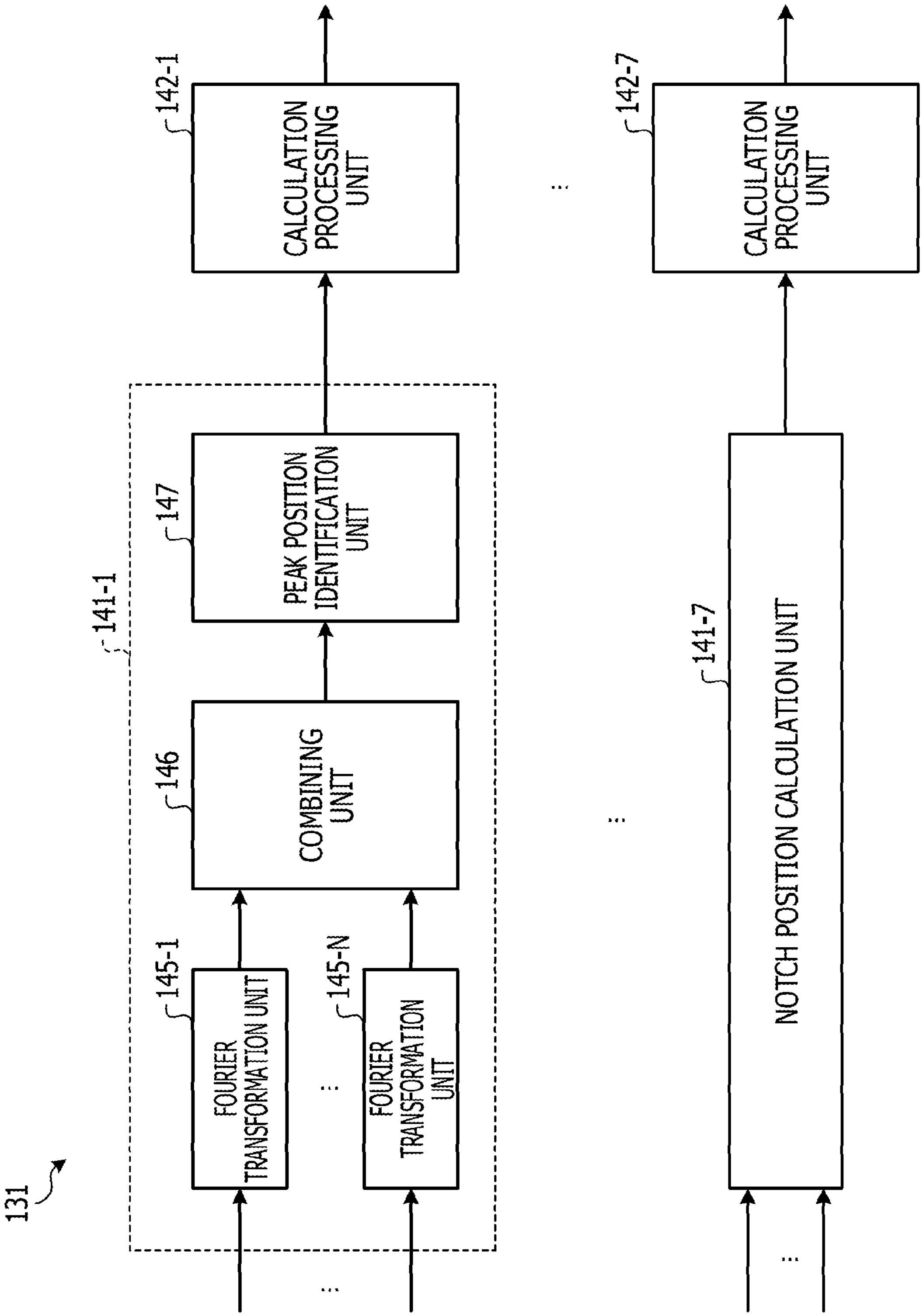

131
141-1
145-1
FOURIER TRANSFORMATION UNIT
145-N
FOURIER TRANSFORMATION UNIT
146
COMBINING UNIT
147
PEAK POSITION IDENTIFICATION UNIT
142-1
CALCULATION PROCESSING UNIT
141-7
NOTCH POSITION CALCULATION UNIT
142-7
CALCULATION PROCESSING UNIT

FIG. 8

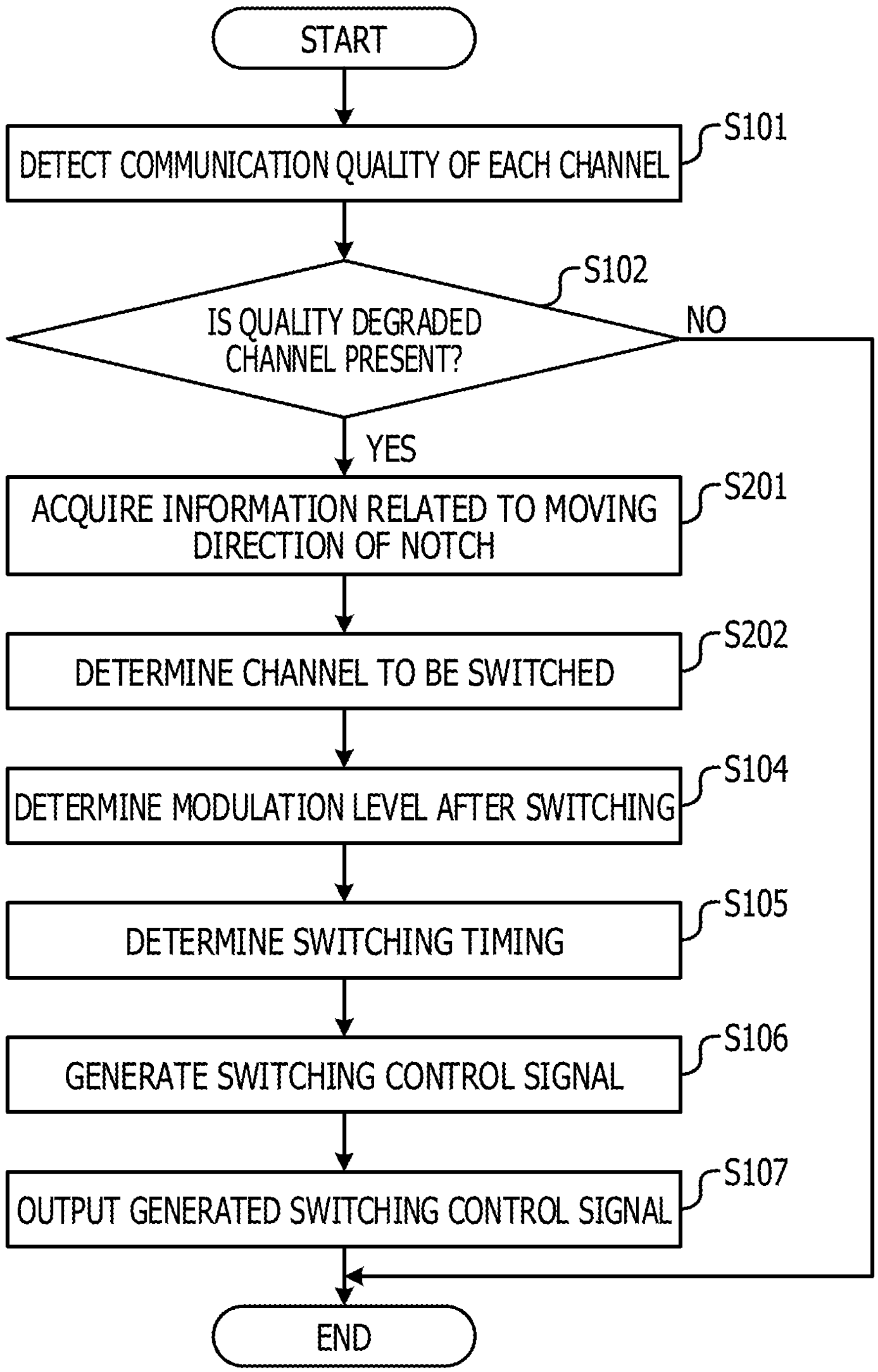

START
DETECT COMMUNICATION QUALITY OF EACH CHANNEL
S101
IS QUALITY DEGRADED CHANNEL PRESENT?
S102
NO
YES
ACQUIRE INFORMATION RELATED TO MOVING DIRECTION OF NOTCH
S201
DETERMINE CHANNEL TO BE SWITCHED
S202
DETERMINE MODULATION LEVEL AFTER SWITCHING
S104
DETERMINE SWITCHING TIMING
S105
GENERATE SWITCHING CONTROL SIGNAL
S106
OUTPUT GENERATED SWITCHING CONTROL SIGNAL
S107
END

FIG. 9

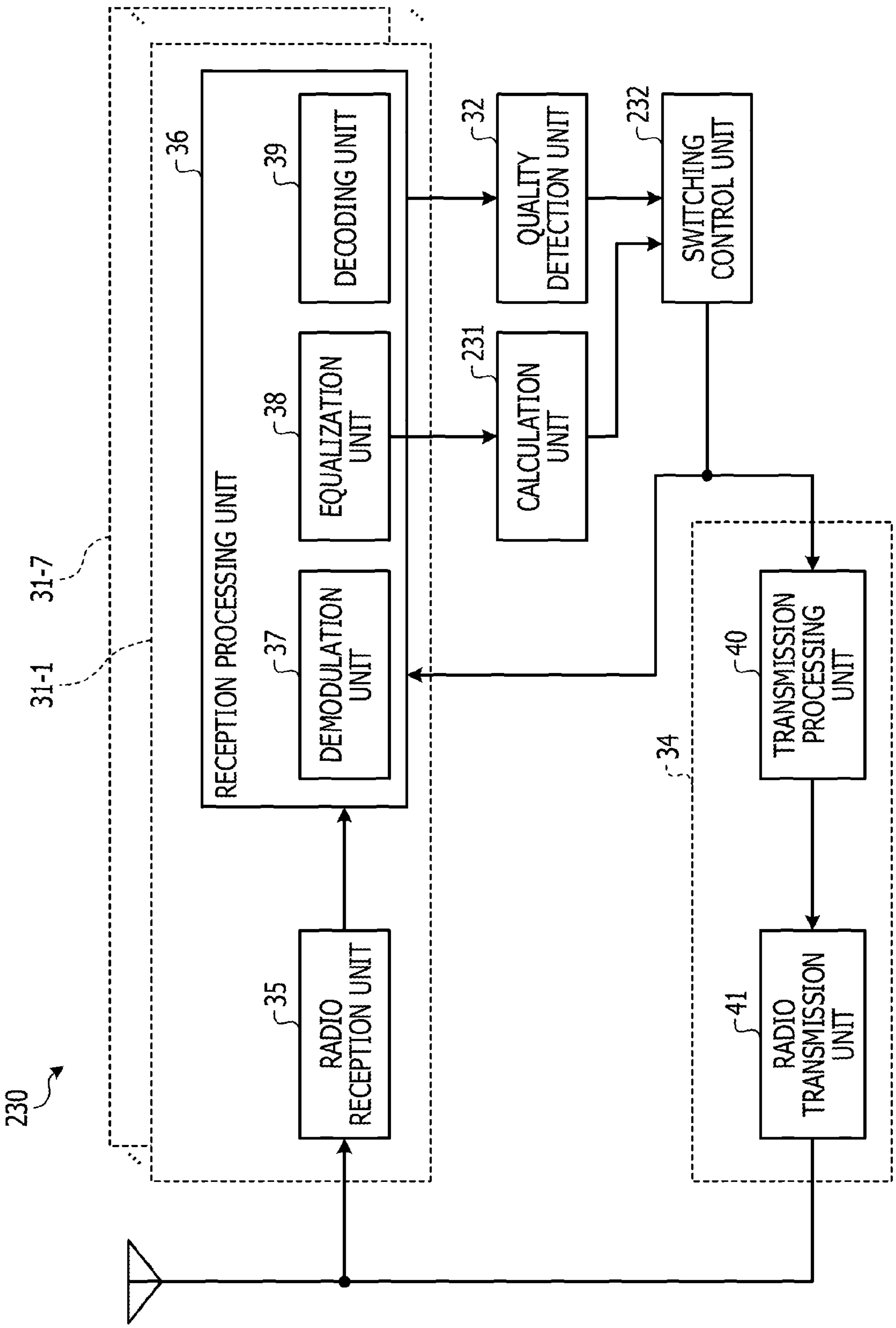

230
31-1
31-7
36
RECEPTION PROCESSING UNIT
35
RADIO RECEPTION UNIT
37
DEMODULATION UNIT
38
EQUALIZATION UNIT
39
DECODING UNIT
231
CALCULATION UNIT
32
QUALITY DETECTION UNIT
232
SWITCHING CONTROL UNIT
34
40
TRANSMISSION PROCESSING UNIT
41
RADIO TRANSMISSION UNIT

FIG. 10

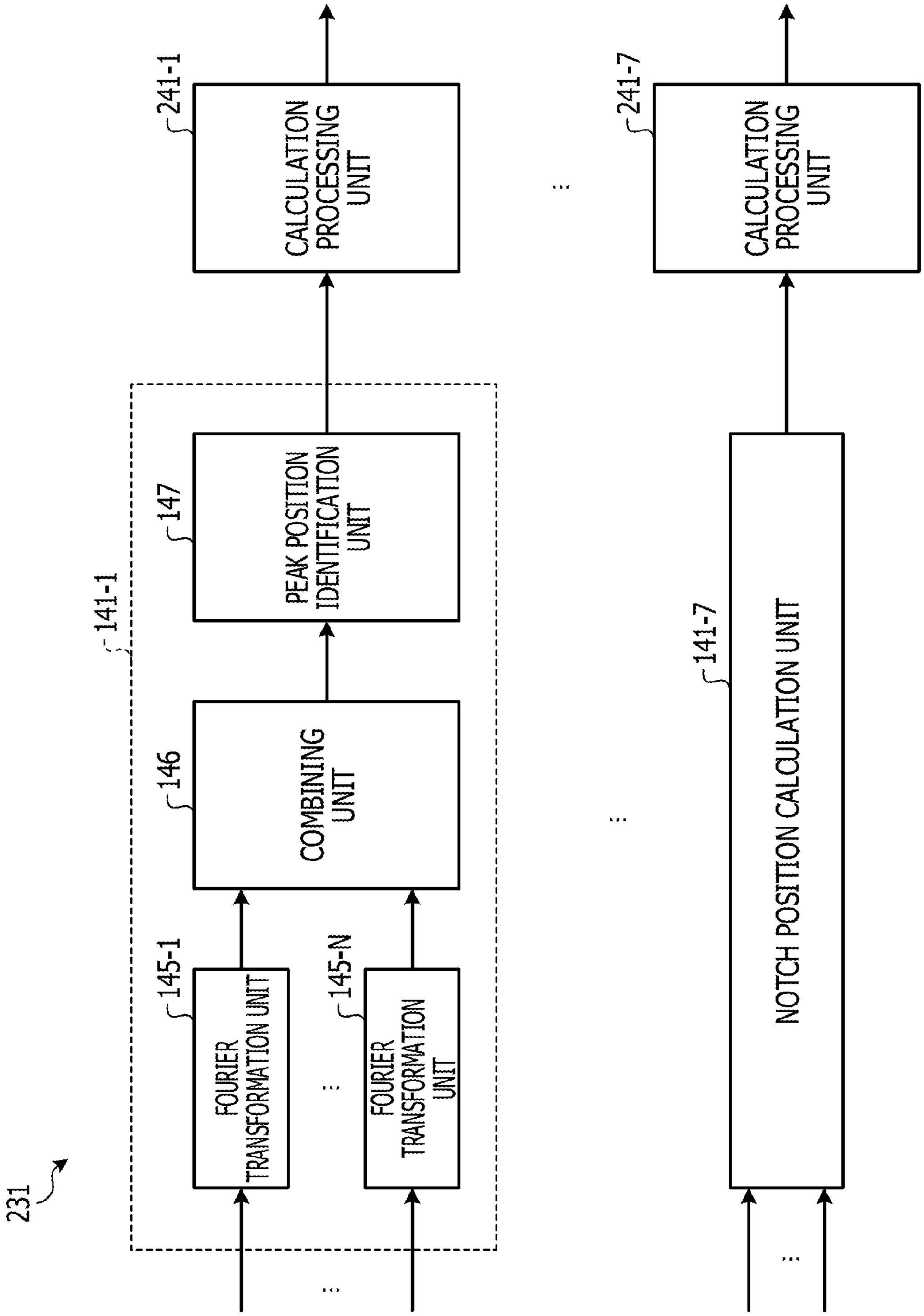
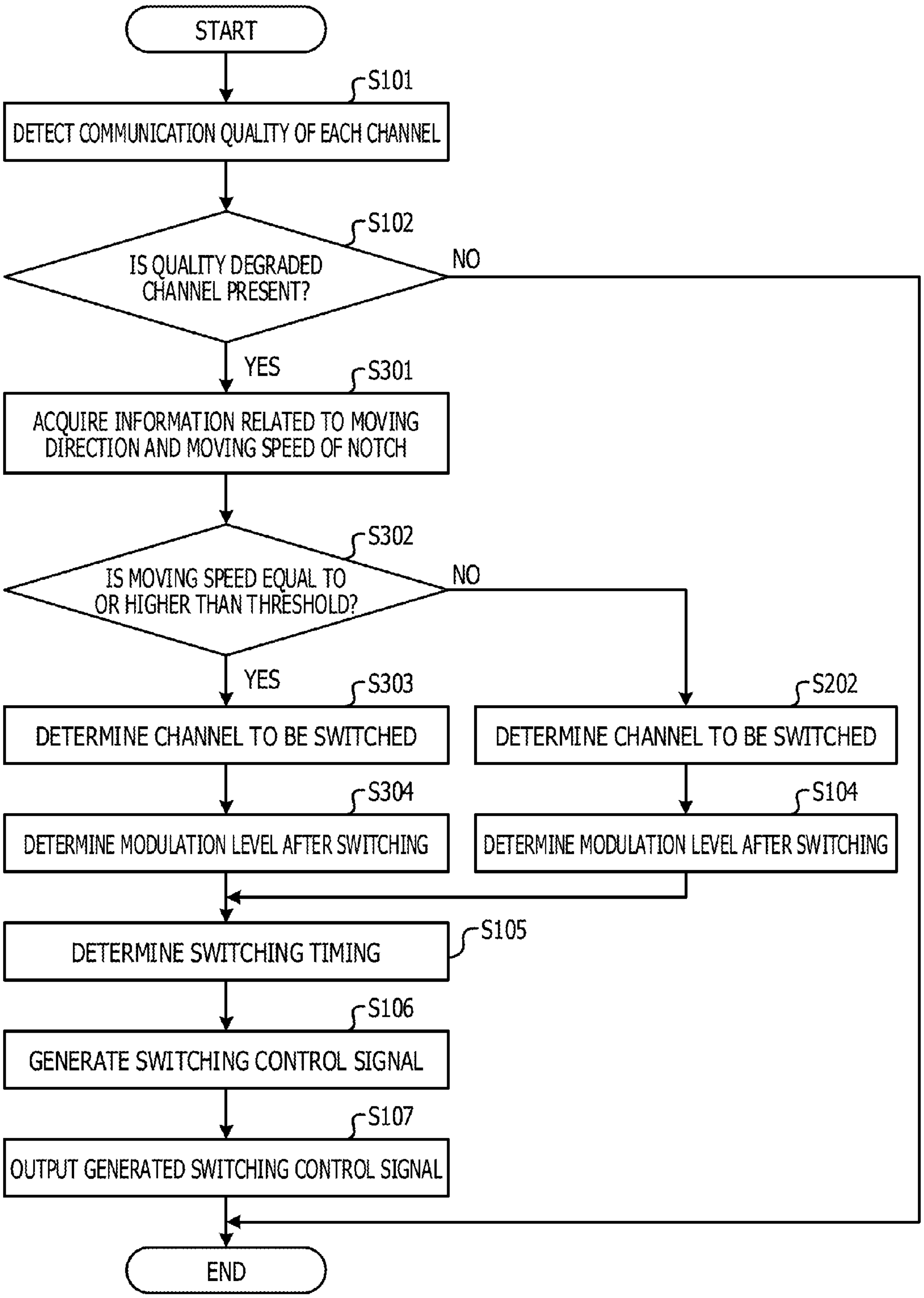
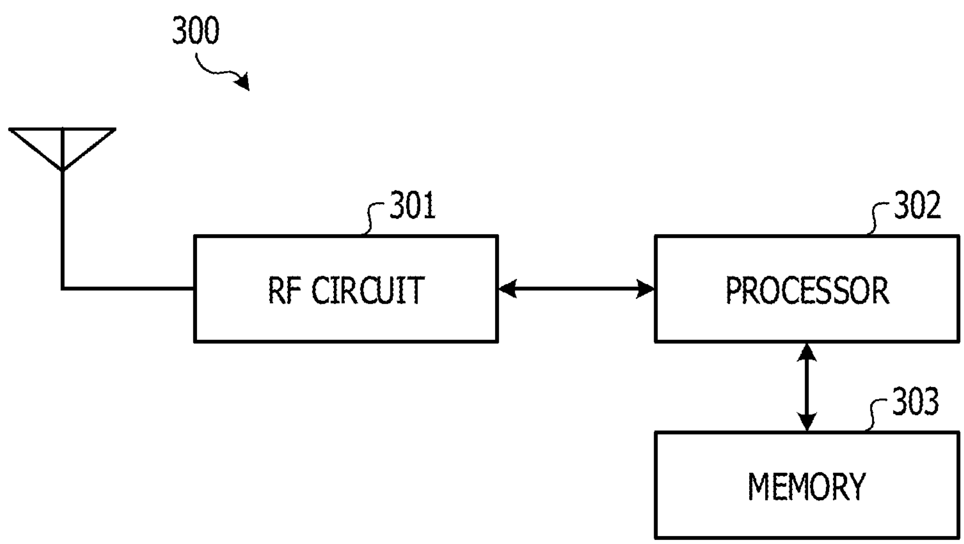

231
141-1
145-1
FOURIER TRANSFORMATION UNIT
145-N
FOURIER TRANSFORMATION UNIT
146
COMBINING UNIT
147
PEAK POSITION IDENTIFICATION UNIT
241-1
CALCULATION PROCESSING UNIT
141-7
NOTCH POSITION CALCULATION UNIT
241-7
CALCULATION PROCESSING UNIT

FIG. 11



START
S101
DETECT COMMUNICATION QUALITY OF EACH CHANNEL
S102
IS QUALITY DEGRADED CHANNEL PRESENT?
NO
YES
S301
ACQUIRE INFORMATION RELATED TO MOVING DIRECTION AND MOVING SPEED OF NOTCH
S302
IS MOVING SPEED EQUAL TO OR HIGHER THAN THRESHOLD?
NO
YES
S303
DETERMINE CHANNEL TO BE SWITCHED
S202
DETERMINE CHANNEL TO BE SWITCHED
S304
DETERMINE MODULATION LEVEL AFTER SWITCHING
S104
DETERMINE MODULATION LEVEL AFTER SWITCHING
S105
DETERMINE SWITCHING TIMING
S106
GENERATE SWITCHING CONTROL SIGNAL
S107
OUTPUT GENERATED SWITCHING CONTROL SIGNAL
END

FIG. 12



RADIO COMMUNICATION DEVICE, RADIO COMMUNICATION METHOD, AND RADIO COMMUNICATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2014-176165, filed on Aug. 29, 2014, the entire contents of which are incorporated herein by reference.

FIELD

The embodiment discussed herein is related to a radio communication device, a radio communication method, and a radio communication system.

BACKGROUND

Between a radio communication device on a transmission side and a radio communication device on a reception side, communication using "adaptive modulation" is performed.

A related technique is disclosed in Japanese Laid-open Patent Publication No. 2011-004118 or Japanese Laid-open Patent Publication No. 2000-151482.

SUMMARY

According to an aspect of the embodiments, a radio communication device includes: a processor configured to execute a program; and a memory configured to store the program, wherein the processor performs, based on the program, operations to: detect communication quality of each of a plurality of channels; and lower a first set modulation level of a first channel with the communication quality which is equal to or lower than a level and a second set modulation level of a first adjacent channel as at least one of two adjacent channels adjacent to the first channel in a frequency axis direction.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates an exemplary radio communication system;

FIG. **2** illustrates an exemplary radio communication device on a transmission side;

FIG. **3** illustrates an exemplary radio communication device on a reception side;

FIG. **4** illustrates an exemplary quality detection unit;

FIG. **5** illustrates exemplary processing performed by a radio communication device on a reception side;

FIG. **6** illustrates an exemplary radio communication device on a reception side;

FIG. **7** illustrates an exemplary calculation unit;

FIG. **8** illustrates exemplary processing performed by a radio communication device on a reception side;

FIG. **9** illustrates an exemplary radio communication device on a reception side;

FIG. **10** illustrates an exemplary calculation unit;

FIG. **11** illustrates exemplary processing performed by a radio communication device; and

FIG. **12** illustrates an exemplary hardware configuration of a radio communication device.

DESCRIPTION OF EMBODIMENTS

For example, a set modulation level applied to communication is switched in accordance with the communication quality. Accordingly, communication throughput may be improved.

Between a radio communication device on a transmission side and a radio communication device on a reception side, communication using a plurality of channels such as frequency bands is performed, and adaptive modulation is performed independently for each channel.

When the frequency position where frequency selective fading occurs moves at a high speed across the channels, with adaptive modulation independent for each channel, the move of the occurrence frequency position may not be followed. Accordingly, the error rate may be increased, whereby the quality of the transmission signals may be lowered.

In embodiments described below, structures having substantially the same or similar functions are denoted by the same reference numerals and overlapping description thereof may be omitted or reduced. Substantially the same or similar processing is denoted by the same reference symbols and overlapping description thereof may be omitted or reduced.

FIG. **1** illustrates an exemplary radio communication system. In FIG. **1**, a radio communication system **1** includes a radio communication device **10** and a radio communication device **30**. The radio communication device **10** may be a radio communication device on a transmission side transmitting a data signal, and the radio communication device **30** may be a radio communication device on a reception side receiving the data signal transmitted from the radio communication device **10**. The radio communication device **10** and the radio communication device **30** may be, for example, backbone devices such as base station devices or relay station devices. The radio communication device **10** and the radio communication device **30** are able to communicate with each other with a plurality of channels such as frequency bands, and communicate using a modulation scheme of the modulation level set for each channel.

The radio communication device **30** detects the communication quality of each channel. The radio communication device **30** performs "switching control" based on the detected communication quality of each channel. For example, under the "switching control", the radio communication device **30** lowers the set modulation level of a channel of which the detected communication quality has been lowered to a certain level or lower (hereinafter, may be referred to as a "quality degraded channel"). Under the "switching control", the radio communication device **30** lowers the modulation level of at least one of two adjacent channels that are adjacent to the quality degraded channel in the frequency direction. For example, the modulation levels of both of the adjacent channels may be lowered, or the modulation level of one of the adjacent channels may be lowered.

For example, the radio communication device **30** generates a "switching control signal" including identification information of a switching target channel of which the modulation level is to be lowered, information indicating the modulation level after being lowered, and information indicating the switching timing such as information indicating a switching start frame. The radio communication device **30** forwards the generated switching control signal to a demodulation unit thereof and transmits the generated switching control signal to the radio communication device **10**.

At a switching timing indicated by the switching control signal transmitted from the radio communication device **30**, the radio communication device **10** switches the modulation scheme of the channel indicated by the switching control signal to the modulation scheme of the modulation level indicated by the switching control signal. At a timing substantially the same as that, switching of modulation schemes may be performed for the same channel also in the demodulation unit of the radio communication device **30**.

As described above, the radio communication device **30** performs switching control that lowers the set modulation levels of the quality degraded channel of which the communication quality has been degraded to a certain level or lower and the channels adjacent to the quality degraded channel. Accordingly, even when the frequency position where frequency selective fading occurs moves at a high speed, adaptive modulation may follow the move. Quality degradation of the transmission signals may be reduced even under high speed moving fading environment.

FIG. **2** illustrates an exemplary radio communication device on a transmission side. In FIG. **2**, the radio communication device **10** includes transmission units **11-1** to **11-7**, a pseudo random noise (PN) pattern signal output unit **12**, and a reception unit **13**. For example, in correspondence with the number of seven channels, seven transmission units **11** may be provided. The number of channels may be any other number.

The transmission units **11-1** to **11-7** correspond to channels **1** to **7** respectively. Each transmission unit **11** includes a transmission processing unit **15** that includes an encoding unit **16** and a modulation unit **17** and a radio transmission unit **18**.

The transmission processing unit **15** performs transmission processing on input transmission data or a PN pattern signal and outputs a signal thus obtained to the radio transmission unit **18**. The transmission processing may include encoding processing performed by the encoding unit **16** and modulation processing performed by the modulation unit **17**. The modulation unit **17** switches modulation schemes for example, set modulation levels based on the "switching control signal" transmitted from the radio communication device **30**. The PN pattern signal may be a known pattern signal.

The radio transmission unit **18** performs predetermined radio transmission processing such as digital-analog conversion or up-converting on the signal output from the transmission processing unit **15** and transmits the radio signal thus obtained via an antenna.

The reception unit **13** includes a radio reception unit **19**, a reception processing unit **20**, and an extraction unit **21**.

The radio reception unit **19** performs radio reception processing such as down-converting or analog-digital conversion on the signal received via the antenna and outputs the signal thus obtained to the reception processing unit **20**.

The reception processing unit **20** performs reception processing such as demodulation and decoding on the signal received from the radio reception unit **19** and outputs the reception data thus obtained to the extraction unit **21**.

The extraction unit **21** extracts the "switching control signal" described above from the reception data received from the reception processing unit **20**. The extraction unit **21** outputs the switching control signal thus extracted to the modulation unit **17** of the transmission unit **11** corresponding to the switching target channel indicated by the switching control signal. With this, the modulation unit **17** having received the switching control signal switches modulation schemes at the switching timing indicated by the switching control signal.

FIG. **3** illustrates an exemplary radio communication device on a reception side. In FIG. **3**, the radio communication device **30** includes reception units **31-1** to **31-7**, a quality detection unit **32**, a switching control unit **33**, and a transmission unit **34**. For example, in correspondence with the number of seven channels, seven reception units **13** may be provided. The number of channels may be any other number.

The reception units **31-1** to **31-7** correspond to the channels **1** to **7** respectively. Each reception unit **31** includes a radio reception unit **35** and a reception processing unit **36** that includes a demodulation unit **37**, an equalization unit **38**, and a decoding unit **39**.

The radio reception unit **35** performs radio reception processing such as down-converting or analog-digital conversion on the signal received via the antenna and outputs the signal thus obtained to the reception processing unit **36**.

The reception processing unit **36** performs reception processing on the signal received from the radio reception unit **35** to obtain reception data. The reception processing may include demodulation processing performed by the demodulation unit **37**, equalization processing performed by the equalization unit **38**, and decoding processing performed by the decoding unit **39**. The demodulation unit **37** switches demodulation schemes such as set modulation levels based on the "switching control signal" output from the switching control unit **33**. The equalization unit **38** may be a transversal equalizer (TRV), for example.

The quality detection unit **32** detects the communication quality of the channel based on a signal component included in the reception data obtained by the reception processing unit **36** and corresponding to the PN pattern signal (hereinafter, may be referred to as a "reception PN pattern signal") and a replica signal of the PN pattern signal. The detection of the communication quality may be performed for each channel. The replica signal of the PN pattern signal may be retained in advance in the quality detection unit **32**.

FIG. **4** illustrates an exemplary quality detection unit. For example, the quality detection unit **32** includes an extraction unit **45**, a bit error detection unit **46**, and a quality calculation unit **47**, as illustrated in FIG. **4**.

The extraction unit **45** extracts the reception PN pattern signal from the reception data obtained by the reception processing unit **36** and outputs the reception PN pattern signal thus extracted to the bit error detection unit **46**.

The bit error detection unit **46** compares the reception PN pattern signal received from the extraction unit **45** and the replica signal of the PN pattern signal to detect a reception error, for example, a bit error.

The quality calculation unit **47** counts the number of reception errors in each determination period for each channel. The quality calculation unit **47** detects the channel of which the number of reception errors in the determination period exceeds a determination threshold such as a quality degraded channel and outputs identification information of the quality degraded channel thus detected to the switching control unit **33**.

The switching control unit **33** illustrated in FIG. **3** determines the quality degraded channel indicated by the identification information received from the quality calculation unit **47** and at least one of the two adjacent channels that are adjacent to the quality degraded channel in the frequency direction to be the switching target channels. The switching control unit **33** generates the "switching control signal" including identification information of the switching target channels, information indicating the modulation level after being lowered, and information indicating the switching timing. The switching control unit **33** outputs the switching control signal thus generated to the demodulation unit **37** and the transmission unit **34**. The set modulation levels of the quality degraded channel and the adjacent channel being the switching targets may be switched to be substantially the same or may be switched to be different. In the case where the set modulation levels are switched to be different, the set modulation level of the quality degraded channel being the switching target may be lowered to a first value and the set modulation level of the adjacent channel being the switching target may be lowered to a second value higher than the first value.

The transmission unit **34** includes a transmission processing unit **40** and a radio transmission unit **41**.

The transmission processing unit **40** performs transmission processing such as encoding and modulation on the switching control signal received from the switching control unit **33** and outputs the transmission signal thus obtained to the radio transmission unit **41**.

The radio transmission unit **41** performs radio transmission processing such as digital-analog conversion or upconverting on the transmission signal output from the transmission processing unit **40** and transmits the radio signal thus obtained via the antenna.

FIG. **5** illustrates exemplary processing performed by a radio communication device on a reception side. The radio communication device on a reception side illustrated in FIG. **3** may perform the processing illustrated in FIG. **5**. The processing illustrated in FIG. **5** may be performed for each determination period described above.

The quality detection unit **32** detects the communication quality of each channel based on the signal received from the reception processing unit **36** corresponding to each channel (operation S**101**).

The quality detection unit **32** determines whether a quality degraded channel is present or not based on the communication quality of each channel thus detected (operation S**102**). For example, the quality detection unit **32** determines whether a channel is present or not of which the detected communication quality has been lowered to a certain level or lower.

When a quality degraded channel is present (Yes at operation S**102**), the switching control unit **33** determines a switching target channel (operation S**103**). For example, the switching control unit **33** determines the quality degraded channel and at least one of the two adjacent channels that are adjacent to the quality degraded channel in the frequency direction to be the switching target channels.

The switching control unit **33** determines a modulation level after switching of the switching target channel (operation S**104**) and determines a switching timing (operation S**105**).

The switching control unit **33** generates a switching control signal including information determined by operations S**103** to S**105** (operation S**106**).

The switching control unit **33** outputs the switching control signal thus generated to the demodulation unit **37** and the transmission unit **34** (operation S**107**).

In the radio communication device **30**, the quality detection unit **32** detects the communication quality of each channel. The switching control unit **33** performs the "switching control" that lowers the set modulation level of the quality degraded channel of which the communication quality detected by the quality detection unit **32** has been lowered to a certain level or lower and the set modulation level of at least one of the two adjacent channels that are adjacent to the quality degraded channel in the frequency axis direction.

In the radio communication device **30**, the quality degraded channel of which the communication quality has been degraded to a certain level or lower and the set modulation levels of the channels adjacent to the quality degraded channel are lowered, and accordingly, even when the frequency position where frequency selective fading occurs moves at a high speed, adaptive modulation may follow the move. Quality degradation of the transmission signals may be reduced even under high speed moving fading environment.

The moving direction of the position of a notch that occurs in the quality degraded channel may be calculated and the modulation level of the adjacent channel present in the calculated moving direction may be lowered.

FIG. **6** illustrates an exemplary radio communication device on a reception side. In FIG. **6**, a radio communication device **130** includes a calculation unit **131** and a switching control unit **132**.

The calculation unit **131** calculates the moving direction of the frequency position of the notch in each channel. The calculation unit **131** outputs the moving direction calculated for each channel to the switching control unit **132**.

For example, the calculation unit **131** acquires a "tap coefficient group" from the equalization unit **38** of the reception unit **31** corresponding to each channel for each calculation timing (calculation period). The calculation unit **131** calculates (identifies) the frequency position of the notch occurrence based on the "tap coefficient group" for each channel. The calculation unit **131** calculates (identifies) the moving direction of the frequency position of the notch based on the frequency position of the notch occurrence calculated at the previous calculation timing and the frequency position of the notch occurrence calculated at this calculation timing for each channel.

FIG. **7** illustrates an exemplary calculation unit. For example, the calculation unit **131** includes notch position calculation units **141-1** to **141-7** and calculation processing units **142-1** to **142-7**, as illustrated in FIG. **7**. Each notch position calculation unit **141** includes Fourier transformation units **145-1** to **145**-N, a combining unit **146**, and a peak position identification unit **147**.

The notch position calculation units **141-1** to **141-7** may correspond to the channels **1** to **7**, respectively. For example, in the notch position calculation unit **141-1**, the Fourier transformation units **145-1** to **145**-N may correspond to tap coefficients **1** to N of the equalization unit **38** of the reception unit **31-1** of the channel **1**, respectively. Each Fourier transformation unit **145** performs Fourier transformation of time fluctuation of a tap coefficient value acquired at the calculation timing and outputs the result thus obtained to the combining unit **146**. The combining unit **146** combines (adds) the result obtained by each of the Fourier transformation units **145-1** to **145**-N and outputs the result thus obtained to the peak position identification unit **147**. The peak position identification unit **147** identifies (calculates) the frequency position where a peak appears in the combined result received from the combining unit **146**.

With the tap coefficient group of the equalization unit **38** undergoing Fourier transformation, the filter characteristic of the equalization unit **38** is calculated. When the notch occurs, with the filter characteristic of the equalization unit **38**, a peak appears in the frequency position of the notch occurrence so as to compensate for the notch. With the peak frequency position of the filter characteristic identified, the frequency position of the notch occurrence is identified.

The calculation processing units **142-1** to **142-7** may correspond to the channels **1** to **7**, respectively. For example, the calculation processing unit **142-1** calculates (identifies) the moving direction of the frequency position of the notch occurrence based on the frequency position of the notch occurrence calculated at the previous calculation timing and the frequency position of the notch occurrence calculated at this calculation timing by the notch position calculation unit **141-1**.

Similarly to the switching control unit **33** illustrated in FIG. **3**, the switching control unit **132** illustrated in FIG. **6** first determines the quality degraded channel indicated by the identification information received from the quality calculation unit **47** to be a switching target channel. The switching control unit **132** determines the channel adjacent to the quality degraded channel and present in the moving direction calculated by the calculation processing unit **142** that corresponds to the quality degraded channel to be another switching target channel. The switching control unit **132** generates a "switching control signal" including identification information of the switching target channel, information indicating the modulation level after being lowered, and information indicating the switching timing. The switching control unit **132** outputs the switching control signal thus generated to the demodulation unit **37** and the transmission unit **34**. The set modulation levels of the quality degraded channel and the adjacent channel being the switching targets may be switched to be the same or may be switched to be different. In the case where the set modulation levels are switched to be different, the set modulation level of the quality degraded channel being the switching target may be lowered to a first value and the set modulation level of the adjacent channel being the switching target may be lowered to a second value higher than the first value.

FIG. **8** illustrates exemplary processing performed by a radio communication device on a reception side. The radio communication device on a reception side illustrated in FIG. **6** may perform the processing illustrated in FIG. **8**. The processing illustrated in FIG. **8** may be performed for each determination period.

When a quality degraded channel is present (Yes at operation S**102**), the switching control unit **132** acquires information related to the moving direction calculated by the calculation processing unit **142** corresponding to the quality degraded channel (operation S**201**).

The switching control unit **132** determines the switching target channel (operation S**202**). For example, the switching control unit **132** determines the quality degraded channel to be the switching target channel. The switching control unit **132** determines the channel adjacent to the quality degraded channel and present in the moving direction indicated by the information acquired by operation S**201** to be the switching target channel.

The switching control unit **132** performs the "switching control" that lowers the modulation level of the quality degraded channel and the modulation level of the channel adjacent to the quality degraded channel that is present in the moving direction of the frequency position of the notch occurred in the quality degraded channel, which has been calculated by the calculation unit **131**.

In the radio communication device **130**, not only the set modulation level of the quality degraded channel of which the communication quality has been degraded to a certain level or lower but also the set modulation level of the channel adjacent to the quality degraded channel that is present in the moving direction of the frequency position where frequency selective fading occurs may be lowered. Accordingly, even when the frequency position where frequency selective fading occurs moves at a high speed, adaptive modulation may follow the move with high accuracy. Quality degradation of the transmission signals may be reduced even under high speed moving fading environment.

For example, the moving direction of the position of the notch occurrence in the quality degraded channel may be calculated and the modulation level of an adjacent channel present in the calculated moving direction may be lowered. The moving speed of the frequency position of the notch occurrence in the quality degraded channel is calculated, and when the calculated moving speed is equal to or higher than the threshold, the set modulation levels of an adjacent channel present in the calculated moving direction and a channel adjacent to the adjacent channel are lowered. For example, the number of the switching target channels may be changed in accordance with the moving speed of the notch frequency position.

FIG. **9** illustrates an exemplary radio communication device on a reception side. In FIG. **9**, the radio communication device **230** includes a calculation unit **231** and a switching control unit **232**.

The calculation unit **231** calculates the moving direction and the moving speed of the frequency position of the notch in each channel. The calculation unit **231** outputs the moving direction and the moving speed calculated for each channel to the switching control unit **232**.

For example, the calculation unit **231** acquires a "tap coefficient group" from the equalization unit **38** of the reception unit **31** corresponding to each channel for each calculation timing (calculation period). The calculation unit **231** calculates (identifies) the frequency position of the notch occurrence based on the "tap coefficient group" for each channel. The calculation unit **231** calculates (identifies) the moving direction and the moving speed of the frequency position of the notch using the frequency position of the notch occurrence calculated at the previous calculation timing and the frequency position of the notch occurrence calculated at this calculation timing for each channel.

FIG. **10** illustrates an exemplary calculation unit. As illustrated in FIG. **10**, the calculation unit **231** includes calculation processing units **241-1** to **241-7**.

The calculation processing units **241-1** to **241-7** may correspond to the channels **1** to **7**. For example, the calculation processing unit **241-1** calculates (identifies) the moving direction of the frequency position of the notch based on the frequency position of the notch occurrence calculated by the notch position calculation unit **141-1** at the previous calculation timing and the frequency position of the notch occurrence calculated at this calculation timing. The calculation processing unit **241-1** calculates the difference between the frequency position of the notch occurrence calculated by the notch position calculation unit **141-1** at the previous calculation timing and the frequency position of the notch occurrence calculated at this calculation timing, such as the moving distance. The calculation processing unit **241-1** divides the calculated moving distance by the time difference between the previous calculation timing and this calculation timing, thereby calculating the moving speed.

The switching control unit **232** illustrated in FIG. **9** may perform the "switching control" similar to that performed by the switching control unit **132** illustrated in FIG. **6** when the moving speed is lower than the threshold. For example, the switching control unit **232** performs "switching control" that lowers the modulation level of the quality degraded channel and the modulation level of the channel adjacent to the quality degraded channel present in the moving direction of the frequency position where the notch occurs in the quality degraded channel, which has been calculated by the calculation unit **231**.

When the moving speed is equal to or higher than the threshold, the switching control unit **232** lowers the set modulation level of a channel adjacent to the adjacent channel. The set modulation levels of the adjacent channel and the channel adjacent to the adjacent channel being the switching targets may be switched to be the same and may be switched to be different. In the case where the set modulation levels are switched to be different, the set modulation level of the adjacent channel being the switching target may be lowered to a second value and the set modulation level of the channel adjacent to the adjacent channel being the switching target may be lowered to a third value higher than the second value. For example, the set modulation level of a channel closer to the quality degraded channel in the frequency axis direction may be made lower.

FIG. **11** illustrates exemplary processing performed by a radio communication device on a reception side. The radio communication device on a reception side illustrated in FIG. **9** may perform the processing illustrated in FIG. **11**. Processing in the flow chart illustrated in FIG. **11** may be performed for each determination period.

When a quality degraded channel is present (Yes at operation S**102**), the switching control unit **232** acquires information related to the moving direction and the moving speed calculated by the calculation processing unit **241** corresponding to the quality degraded channel (operation S**301**).

The switching control unit **232** determines whether the moving speed indicated by the information thus acquired is equal to or higher than the threshold (operation S**302**).

When the moving speed is equal to or higher than the threshold (Yes at operation S**302**), the switching control unit **232** determines the switching target channel (operation S**303**). For example, the switching control unit **232** determines the quality degraded channel, the adjacent channel present in the moving direction of the frequency position of the notch occurrence in the quality degraded channel, which has been calculated by the calculation unit **231**, and the channel adjacent to the adjacent channel to be the switching target channels.

The switching control unit **232** determines the modulation level after switching of the switching target channels (operation S**304**). For example, the switching control unit **232** may lower the set modulation level of the quality degraded channel to a first value, lower the set modulation level of the adjacent channel to a second value higher than the first value, and lower the set modulation level of the channel adjacent to the adjacent channel to a third value higher than the second value. When the moving speed is lower than the threshold (No at operation S**302**), the switching control unit **232** performs operation S**202** and operation S**104**.

In the radio communication device **230**, when the moving speed of the frequency position of the notch occurrence in the quality degraded channel is equal to or higher than the threshold, the switching control unit **232** determines the quality degraded channel, the adjacent channel present in the moving direction of the frequency position of the notch occurrence in the quality degraded channel, which has been calculated by the calculation unit **231**, and the channel adjacent to the adjacent channel to be the switching target channels.

In the radio communication device **230**, when the moving speed of the notch frequency position is high, not only the set modulation levels of the quality degraded channel and the adjacent channel but also the set modulation level of the channel adjacent to the adjacent channel may be lowered. Accordingly, even when the frequency position where frequency selective fading occurs moves at a high speed, adaptive modulation may follow the move with high accuracy. Quality degradation of the transmission signals may be reduced even under high speed moving fading environment.

The switching control unit **232** lowers the set modulation level of the adjacent channel to the second value and lowers the set modulation level of the channel adjacent to the adjacent channel to the third value higher than the second value.

In the radio communication device **230**, the farther from the quality degraded channel, the smaller the amount of the lowered set modulation level is set. Accordingly, excessive lowering of the set modulation level of a channel having time until frequency selective fading occurs may be reduced.

The communication quality of the channels may be detected based on the PN pattern signal. For example, the communication quality of the channels may be detected based on the distribution on the constellation of the reception signal points when the signal transmitted from the radio communication device on a transmission side is received by the radio communication device on a reception side, for example.

All or any part of various elements in each of the units described above may be distributed/integrated functionally or physically in any units in accordance with various loads, use conditions, and other factors.

All parts or any part of various processing functions performed in each device may be performed on a central processing unit (CPU) or a microcomputer such as a micro processing unit (MPU) and a micro controller unit (MCU). All parts or any part of various processing functions may be performed on a program analyzed and executed by a CPU or a microcomputer such as an MPU, and a MCU, or on hardware by wired logic.

The radio communication devices described above may include a hardware configuration as described below, for example.

FIG. **12** illustrates an exemplary hardware configuration of a radio communication device. As illustrated in FIG. **12**, the radio communication device **300** includes a radio frequency (RF) circuit **301**, a processor **302**, and a memory **303**. The processor **302** may be a CPU, a digital signal processor (DSP), or a field programmable gate array (FPGA), and so on. The memory **303** may be a random access memory (RAM) such as a synchronous dynamic random access memory (SDRAM), a read only memory (ROM), or a flash memory. Each of the radio communication devices **10**, **30**, **130**, and **230** may include the configuration illustrated in FIG. **12**.

Various processing functions performed in the radio communication devices described above may be implemented by executing, by a processor, programs stored in various memories such as non-volatile storage media. For example, the memory **303** may store therein programs corresponding to processing performed by the PN pattern signal output unit **12**, the transmission processing unit **15**, the reception processing unit **20**, and the extraction unit **21**, and the processor **302** may perform each of the programs. The memory **303** may store therein programs corresponding to processing performed by the quality detection unit **32**, the switching control units **33**, **132**, **232**, the reception processing unit **36**, the transmission processing unit **40**, and the calculation units **131** and **231**, and the processor **302** may perform each of the programs. The radio transmission unit **18** and the radio reception unit **19** may be implemented by the RF circuit **301**. The radio reception unit **35** and the radio transmission unit **41** may be implemented by the RF circuit **301**.

Various processing functions performed by the radio communication devices may be performed by the processor **302**, and may be performed by a plurality of processors.

All examples and conditional language recited herein are intended for pedagogical purposes to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although the embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A radio communication device comprising:
- a processor configured to execute a program; and
- a memory configured to store the program,
- wherein the processor performs, based on the program, operations to:
- detect communication quality of each of a plurality of channels; and
- lower a first set modulation level of a first channel with the communication quality which is equal to or lower than a level and a second set modulation level of a first adjacent channel which corresponds to one of two adjacent channels adjacent to the first channel in a frequency axis direction.

2. The radio communication device according to claim **1**, wherein the processor detects the communication quality based on a PN pattern signal included in reception data.

3. The radio communication device according to claim **1**, wherein the processor calculates a moving direction of a frequency position of a notch occurred in the first channel and lowers the second set modulation level of an adjacent channel present in the moving direction as the first adjacent channel.

4. The radio communication device according to claim **3**, wherein the processor acquires the moving direction based on a first frequency position of the notch calculated at a first calculation timing and a second frequency position of the notch calculated at a second calculation timing.

5. The radio communication device according to claim **1**, wherein the processor calculates a moving direction and a moving speed of a frequency position of a notch occurred in the first channel, lowers the second set modulation level of an adjacent channel present in the moving direction as the first adjacent channel, and determines whether or not to lower a third set modulation level of a second adjacent channel adjacent to the first adjacent channel based on the moving speed.

6. The radio communication device according to claim **5**, wherein the processor lowers the third set modulation level of the second adjacent channel when the calculated moving speed is equal to or higher than a threshold.

7. The radio communication device according to claim **1**, wherein the processor lowers the first set modulation level of the first channel to a first value and lowers the second set modulation level of the first adjacent channel to a second value higher than the first value.

8. A radio communication method comprising:
- detecting communication quality of each of a plurality of channels; and
- lowering, by a processor, a first set modulation level of a first channel with the communication quality which is equal to or lower than a level and a second set modulation level of a first adjacent channel which corresponds to one of two adjacent channels adjacent to the first channel in a frequency axis direction.

9. The radio communication method according to claim **8**, wherein the detecting is performed based on a PN pattern signal included in reception data.

10. The radio communication method according to claim **8**, further comprising:
- calculating a moving direction of a frequency position of a notch occurred in the first channel; and
- lowering the second set modulation level of an adjacent channel present in the moving direction as the first adjacent channel.

11. The radio communication method according to claim **10**, further comprising:
- acquiring the moving direction based on a first frequency position of the notch calculated at a first calculation timing and a second frequency position of the notch calculated at a second calculation timing.

12. The radio communication method according to claim **8**, further comprising:
- calculating a moving direction and a moving speed of a frequency position of a notch occurred in the first channel; and
- lowering the second set modulation level of an adjacent channel present in the moving direction as the first adjacent channel; and
- determining whether or not to lower a third set modulation level of a second adjacent channel adjacent to the first adjacent channel based on the moving speed.

13. The radio communication method according to claim **12**, wherein the third set modulation level is preformed when the calculated moving speed is equal to or higher than a threshold.

14. The radio communication method according to claim **8**, the first set modulation level is lowered to a first value and the second set modulation level is lowered to a second value higher than the first value.

15. A radio communication system comprising:
- a second radio communication device on a reception side communicable with a first radio communication device on a transmission side via a plurality of channels,
- wherein the second radio communication device:
- detects communication quality of each of the plurality of channels; and
- lowers a first set modulation level of a first channel with the communication quality which is equal to or lower than a level and a second set modulation level of a first adjacent channel which corresponds to one of two adjacent channels adjacent to the first channel in the frequency axis direction.

16. The radio communication system according to claim **15**, wherein the second radio communication device detects the communication quality based on a PN pattern signal included in reception data.

17. The radio communication system according to claim **15**, wherein the second radio communication device calculates a moving direction of a frequency position of a notch occurred in the first channel and lowers the second set modulation level of an adjacent channel present in the moving direction as the first adjacent channel.

18. The radio communication system according to claim **17**, wherein the second radio communication device acquires the moving direction based on a first frequency position of the notch calculated at a first calculation timing and a second frequency position of the notch calculated at a second calculation timing.

19. The radio communication system according to claim **15**, wherein the second radio communication device calculates a moving direction and a moving speed of a frequency position of a notch occurred in the first channel, lowers the second set modulation level of an adjacent channel present in the moving direction as the first adjacent channel, and determines whether or not to lower a third set modulation level of a second adjacent channel adjacent to the first adjacent channel based on the moving speed.

20. The radio communication system according to claim **15**, wherein the second radio communication device lowers the first set modulation level of the first channel to a first value and lowers the second set modulation level of the first adjacent channel to a second value higher than the first value.

* * * * *